R. H. MANN.

The Association
of
Engineering and Shipbuilding Draughtsmen.

LAND SURVEYING AND LEVELLING.

By IAN ROBB, A.M.I.Struct.E., A.R.T.C. (Salford).

Published by The Association of Engineering and Shipbuilding Draughtsmen
Onslow Hall, Little Green, Richmond, Surrey.

SESSION 1947-48.

Printed by Milne, Tannahill & Methven, Ltd. (T.U.), 12-14 Mill Street, Perth.

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LIST OF ILLUSTRATIONS

PREFACE

THE practice of land surveying and levelling covers such a wide range of methods and instruments that it is beyond the scope of a pamphlet of this nature to do full justice to the subject. Nevertheless, it is hoped that the choice of principles, instruments and methods explained, will cover the more elementary and everyday applications of engineering surveying.

The writer wishes to express his indebtedness and thanks to Messrs. W. F. Stanley & Co., Ltd., of London, for placing at his disposal technical information from which the diagrams and text on the dumpy level and transit theodolite have been prepared. Figs. 18 and 31 are diagrammatic and must not be taken as being a true representation of this company's products.

I. R.

MANCHESTER, 1947.

R. H. MANN.

LAND SURVEYING AND LEVELLING.

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FUNDAMENTAL PRINCIPLES.

Definition.

In general the practice of land surveying and levelling implies the measurement of some part of the earth's surface and plotting the resulting measurements to a reduced scale on a drawing or chart.

A survey may be prepared for various purposes, such as :—

(*a*) To obtain areas of certain pieces of land ;
(*b*) To illustrate legal documents and Parliamentary Bills ;
(*c*) For the use of civil engineer, architect or builder in connection with some building project ;
(*d*) For military, geological or geographical purposes.

The measurement of horizontal distances may be referred to as "surveying" and the vertical measurement of differences in height occurring on the earth's surface as "levelling."

Plane and Geodetic Surveying.

In plane surveying, the surface of the earth is assumed to be a horizontal plane. Obviously, this representation is false, because it takes no account of the curvature of the earth's surface, but as this discrepancy is negligible in surveys of up to about 100 square miles it can be discounted within the scope of everyday surveying. When considering surveys on a national basis this error must be eliminated and a geodetical survey prepared.

Field and Office Work.

Surveying falls into two distinct divisions :—

(*a*) Field Work. Visiting the actual plot of ground, deciding on procedure, taking dimensions and levels required and recording these in a systematic manner.

(*b*) Office Work. To produce a drawing showing either in plan or sectional elevation (according to requirements) a scale representation of the ground surveyed from the measurements taken in the field. The purpose for which the survey is required will decide the scale and the amount of detail shown.

Principles of Surveying.

To enable a drawing to be prepared, certain measurements will have to be taken in the field. Such measurements must fix accurately the position of required points.

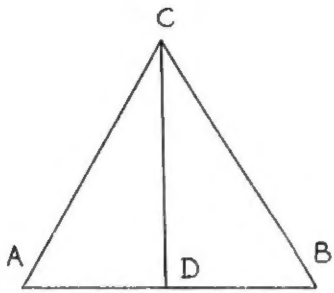


Fig. 1.

In Fig. 1 it is required to fix the position of the point C in relation to the other points A and B. This could be done by measuring all three sides of the triangle ABC, or by measuring the base line AB and the angles at A and B. A third and less satisfactory method would be to erect a perpendicular CD to the base line AB and the measurement of AD, DB and CD would fix the position of C.

DESCRIPTION AND USE OF EQUIPMENT FOR TAKING LINEAR MEASUREMENTS.

Chains.

Two types of chain are in common use in this country, (*a*) Gunter's chain, 66 feet long, (*b*) Engineer's chain, 100 feet long. Both chains are sub-divided into 100 links.

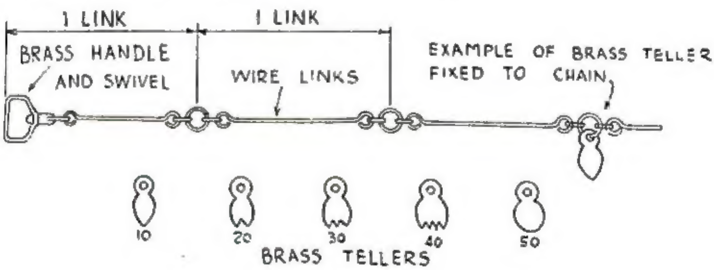


Fig. 2.

The chain links are formed from iron or steel wire in varying aguges, roughly 0·1 inches in dia. At each end of the chain a brass handle and swivel are fitted.

When taking measurements with an extended chain, the number of whole links must be counted and the remaining fraction of a link estimated to give the required length. To obviate tedious counting of the links from either end ot the chain, brass tellers are fixed every 10 links along the chain. It will be noted that the tellers repeat from each end of the chain, allowing both ends to be used as zero. Care must be taken when reading the tellers not to confuse the 40 feet and 60 feet tellers with each other, due to their similarity.

Gunter's chain, named after the originator, is one *chain*, or 22 yards in length, 80 chain lengths equalling one mile or 10 square chains equalling one acre. For measurements of this sort, Gunter's chain is ideal, but for the measurement of distances in feet, the length of each link being 0·66 feet, the conversion of links into feet becomes a necessity and is an additional labour.

In this latter case, it will be found advantageous to use the engineer's chain, as each link is one foot long and a direct reading in feet can be obtained. When estimating fractions of a link in the engineer's chain, a greater degree of accuracy can be obtained if a pocket foot-rule is carried and applied to the chain when required.

An alternative to the types of chain described above is the "band chain." In place of the wire links a steel ribbon is employed about $\frac{5}{8}$-ins. in width and 1/50 ins. thick. Brass handles and swivels are fitted and the whole is wound on to a reel similar in type to that used in the cinematograph industry. The link divisions are marked either with brass studs let in to the chain or by etching.

Comparing the two types of chain, the following points emerge :

	Wire Link Chain.	*Steel Band Chain.*
1.	Each link tends to stretch, rendering the chain inaccurate.	Far less likely to stretch.
2.	Will withstand rough usage and it is easily repaired if broken in the field.	Site repairs difficult if broken. Has a tendency to kink.
3.	100 feet iron wire chain heavy to handle.	Corresponding steel band lighter in weight.
4.	Not affected by dirt unless it lodges between links and affects length.	If link divisions are etched, constant cleaning and oiling are required to prevent rust.

Measuring Tape.

These are obtainable in various stock lengths up to 100 feet long and are of the following types :—

1. *Linen tape.* The disadvantages of the linen measuring tape are its tendency to shrink when wet, to stretch when in use and to become dirty and illegible. Much favoured by builders, but should not be used if accurate work is desired.

2. *Metallic tape.* Similar to the linen tape, but brass or copper wires are woven in to offset the tendency of the linen to stretch.

3. *Steel tape.* Very superior to the linen or metallic tapes, but must be kept clean and oiled if etched markings are to remain easily readable.

A 66 feet or 100 feet steel tape, about ½-in. wide and marked in feet and inches on one face and Gunter's links on the other, will cover all requirements likely to be encountered,

At the zero end of the tape, a steel or brass ring is attached and the whole is wound on to a spindle housed in a leather or bakelite case.

Care should be taken to ensure that any assistant detailed to hold the zero end of the tape understands that the front face of the ring is zero and that it must not be folded back on itself before use.

Ranging Rods.

Ranging rods are used for three main purposes.

(*a*) For marking survey points.
(*b*) "Lining in" intermediate points on a straight line.
(*c*) As a rough measuring stick.

The construction consists of a wooden or light metal alloy pole, about 1¼ ins. dia. and 7 feet long, pointed and iron shod at the lower end for insertion into soft ground. To enable the rod to be seen against varying backgrounds, coloured rings, each one foot deep, are painted along its length. Colours may vary, but the most usual system is alternating red, white and black bands.

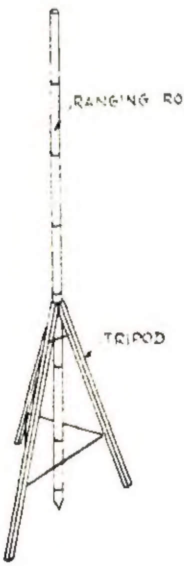


Fig. 3.

In soft ground the pointed end can be inserted. When a survey point is required to have some degree of permanency, a pointed hollow tube up to 1 foot long can be driven in flush with the ground or tarmac surface and the ranging rod inserted and removed as necessary. For hard concrete or rock surfaces a tripod can be used, as shown in Fig. 3.

Arrows.—Manufactured in sets of ten from steel wire about 3/16 ins. thick, pointed at one end and formed into an eye at the other, making the complete arrow about 2 feet long. Used in laying down a chain line, but numerous uses will be found for this useful item of equipment.

Using a chain, ranging rods and arrows to measure a fixed distance.—It is desired to obtain the distance between two points A and B lying several chain lengths apart.

For this operation the surveyor (termed the "follower") will require an assistant (termed the

"leader"). The follower standing at point A instructs the leader to take a ranging rod and a set of arrows, and stand slightly less than one chain length away in the direction of point B, holding the rod upright. By instructing the leader to move either to the left or right, the follower can line in the rod with point B. A point having been established on the line AB, one chain length is measured along the line, and the leader marks his end of the chain with an arrow. The leader then draws the chain forward and the follower advances to the ranging rod previously erected by the leader.

A second rod is then lined in with point B and a second chain length laid down and marked with an arrow. As the follower advances after the second chain length has been measured he picks up the arrow left by his leader. This procedure is repeated until the line has been chained for its full length. The number of arrows held by the follower will represent the number of chain lengths measured, and this number, plus any fraction of a chain length required to close the two points, will represent the measured length from A to B.

The chain, when used for laying the first length, can be "thrown out" by retaining the two handles in one hand and throwing out the bundle of links with the other. Before reading each chain length, always make sure that the chain is taut and free from any kinks or distortions.

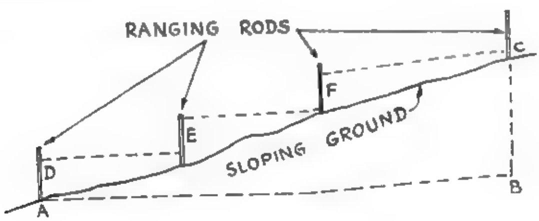


Fig. 4.

Chaining or Measuring on Sloping Ground.

When measurements are required on sloping ground, it must be remembered that in plane surveying the length required for office plotting is not length AC, measured along the slope, but the horizontal distance AB (see Fig. 4). Two methods of obtaining length AB are :—

(a) *By taking stepped dimensions.*

A series of ranging rods are erected in line up the slope. The distance is then measured in a series of steps DE, EF and FG, the addition of all three being equivalent to AB. Care must be taken to ensure :—

(1) That ranging rods are erected vertically with the aid of a plumb bob.

(2) That for ease in measuring, the distance AE set out between the ranging rods does not cause the height AD to rise above shoulder level.

(3) That the measuring tape or chain is kept taut and horizontal. A steel tape will be much easier to pull taut than a wire chain, although it may be necessary to hold the ends of the tape with both hands. Should this be necessary, care must be taken to ensure that the line and tension of the tape is not disturbed by the introduction of the other hand.

(b) *Using a clinometer.*

By using a clinometer the angle CAB can be observed, the length AC measured and length AB calculated by simple trigonometry. The use of the clinometer is described in the following section.

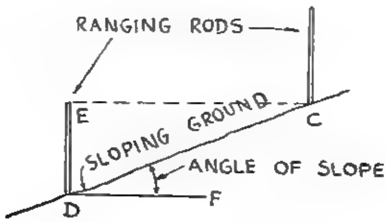


Fig. 5.

Measuring Angles on Sloping Ground.

(a) *Using right-angled triangles.*

Erect two ranging rods along the line of slope and measure the distance EC (see Fig. 5). A right-angled triangle ECD is formed in which EC and ED, or EC and DC are measured and the angle ECD calculated. The angle ECD equals angle CDF, which is the required angle of slope.

(b) *Using a clinometer.*

The most widely known of the clinometers is the Abney Level (see Fig. 6) ; the essential features are :—

(1) A square sighting tube containing a mirror fixed at 45 degrees to the line of sight and a cross hair on the line of sight.

(2) A scale graduated in degrees mounted on the sighting tube.

(3) A moveable bubble level and pointer controlled by a finger screw.

Divided vertically into two, the mirror is silvered only on one half, the other half being left clear glass. This enables a reflection

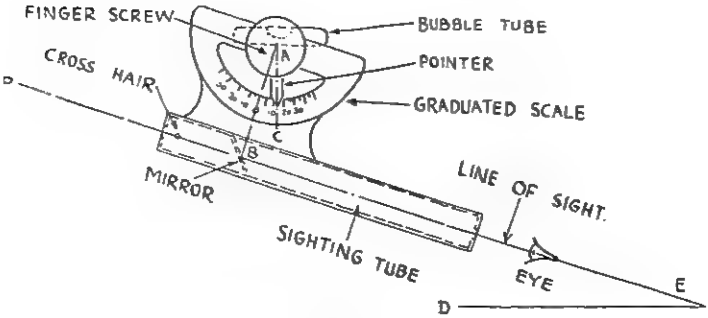


Fig. 6.

of the bubble tube to be seen at the same time as a distant point viewed along the line of sight.

To use the instrument a sight is taken on to a distant point up the slope (*e.g.*, a mark on a ranging rod) set at a height above the ground equal to the eye level of the observer. The finger screw is then rotated until the centre of the bubble is observed to be in the "middle" or "zero" position of its run, and its centre line to coincide with the cross hair along the line of sight to the distant mark. The angle through which the instrument has been turned to keep the bubble level is the required angle of slope. This angle BAC (which equals angle PED) can be read directly from the scale.

Should the accuracy of the instrument be in doubt, the angle of slope should be measured from the top as well as from the base of the slope. The two readings can then be compared and an average result obtained. Any error in the instrument can be corrected by adjusting the level of the bubble tube, using the screws provided for this purpose.

The accuracy of the readings depends upon the ability of the observer to remain steady whilst using the instrument.

For more accurate work the theodolite will be required.

Fixing a Point from a Survey Line by means of Offsets and Tie Lines.

The outline of any feature, *e.g.*, a hedge, as shown in Fig. 7, can be related to a survey line by means of offsets. These are measured at right angles from the survey line to the feature, at measured intervals along the survey line. Offsets should be kept within 30 feet in length and the right angle condition can be estimated by eye. For longer offsets a cross staff or optical square should be utilised. (See "Devices used for setting out right angles"). The proposed scale of plotting should be borne in mind when taking offsets, for instance, it would be a waste of time to take offsets every 10 feet along a survey line when the scale of plotting was to be small, *e.g.*, 3 ins. to the mile.

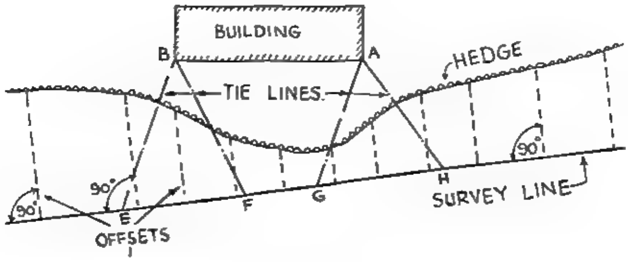


Fig. 7.

Offset taking should be dovetailed into the process of laying down a chain or survey line described in the previous sections. As each chain length is laid down, any offsets required should be taken.

Objects lying farther away from the chain line can be related by the use of tie lines. The corners of the square building A and B can be related to the survey line by obtaining the lengths AG and AH to point A and BE and BF to point B. The positions of E, F, G and H along the chain line must, of course, be known.

Devices used for setting out Right Angles.

Circumstances may call for the setting out of a right angle. For instance, to ensure that a long offset has been taken at right angles to a survey line, or the desirability of having two survey lines running at 90 degrees to each other.

(a) *By setting out a "3 : 4 : 5 triangle."*

This method makes use of the property of a triangle having sides in the proportion 3 : 4 : 5 being right angled.

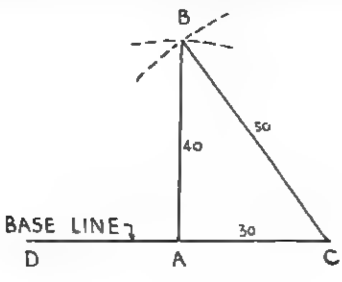


Fig. 8.

In practice the following procedure will be found most convenient :—

(1) Insert two wooden pegs along the base line, say 30 feet apart at A and C, and knock in a nail in the centre of each peg allowing 1-in. of nail to project.

(2) At A and C hook the ring of a measuring tape to the peg nails and sweep out arcs of 40 feet and 50 feet respectively.

The intersection of the two arcs will establish point B, giving the line AB at 90 degrees to base line AC.

(*b*) *By Cross Staff.*

Two types of cross staff are shown in Fig. 9 (a) and 9 (b). Both types have fixed sighting slots provided at 90 degrees to each other.

The cross staff in Fig. 9 (a) is erected on a short ranging rod placed at A (see Fig. 8) and one line of sight fixed along the base line AC. By viewing along the opposing sight an assistant holding a ranging rod vertically at B can be "lined in," fixing the line AB perpendicular to the base line AC.

A more elaborate fixture is illustrated in Fig. 9 (b). By sighting through a narrow slit on face A a hair line in the opposing wide slit on face B can be used to fix a sight line. The narrow slits on the 45 degree faces can be used for setting out lines at 45 degrees to the base lines.

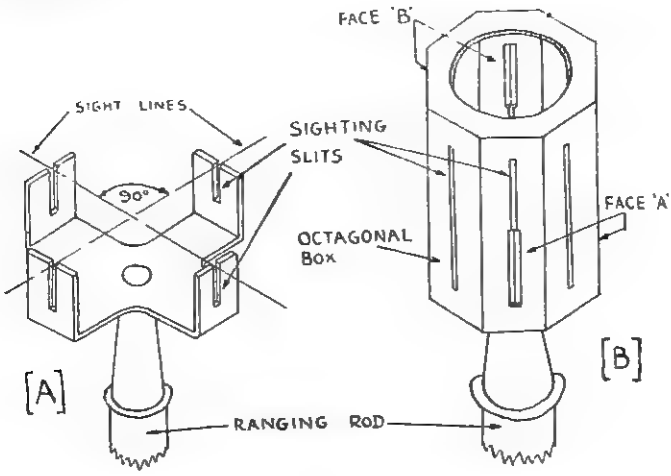


Fig. 9.

An obvious disadvantage of the cross staff is the short distance between the sighting and viewing slits, giving the instrument a short sighting base and inaccuracy.

(c) *By Optical Square.*

For setting out perpendicular lines to a base line the pocket optical square is much more accurate than the cross staff.

Housed in a circular box, approximately 2 ins. in diameter and ¾-ins. in depth, the optical square contains two mirrors set at 45

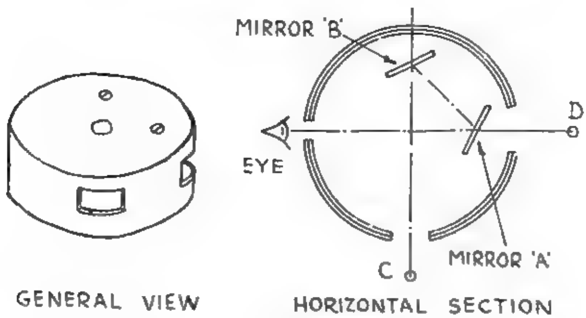


Fig. 10.

degrees to each other (see Fig. 10). Mirror A is divided horizontally into a silvered and a clear half, mirror B is fully silvered.

The eye can see objects at D through the instrument because mirror A is half clear and can also see objects at C reflected by mirror B to the silvered half of mirror A.

To use the instrument, place it centrally upon a short ranging rod erected at A (see Fig. 11), and view a ranging rod erected at point C on the base line. Give instructions to an assistant holding a ranging rod at point D to move either to the right or left until the reflected image of the rod is seen to coincide with the rod at C. The line AD will then be at right angles to base line BC.

When not in use the two halves of the instrument can slide past each other, closing the sight holes and protecting the interior from dirt.

Should the accuracy of the instrument be doubted the following method should be used. From A (Fig. 11), view C and line in a rod at D. Reverse position, view B and line in a second rod at D. If the instrument is in correct adjustment, both points established at D will coincide. Should this not be the case, the correct point D will lie equidistant between the two results. To adjust the instrument, angles of the mirrors can be altered by turning the screws provided on exterior of the case.

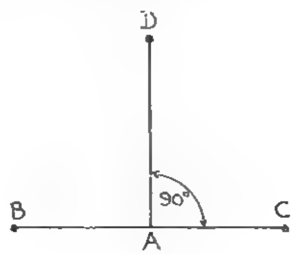


Fig. 11.

CHAIN SURVEYS.

Principle.—In Fig. 1 it was shown that the points A, B and C could be fixed in relation to each other by measuring the sides of the triangle formed by joining the points. A plot of land ABCDE in Fig. 12 could be surveyed by dividing it into a series of triangles and measuring the three sides of each triangle. From the data obtained it would be possible to make an accurate drawing of the boundaries of the land by plotting the system of triangles. This system of triangulation, in which only linear dimensions are taken, forms the basis of the chain survey.

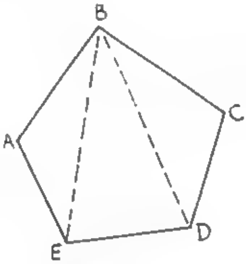


Fig. 12.

Before commencing a survey it is necessary to set up a number of control points or stations. Points A, B, C, D and E (Fig. 12) serve the function of stations, as all dimensions required have been taken from these points.

Scope.

The chain survey is ideally suited for measuring small plots of land (*e.g.*, building sites, small farms, etc.) which are comparatively level and have simple detail.

Assuming Fig. 13 to be a plot of land under survey, it is advisable to pay a preliminary visit to the site and become acquainted with the conditions and formulate a plan for carrying out the work. Prior consideration of the work in hand may save valuable time as compared with a hurriedly conceived plan which may develop difficulties later.

The shape of the plot being irregular it will be necessary to establish a number of stations and lay down a series of main survey lines, positioning the adjacent detail by taking offsets.

Equipment.

Although the use of the chain for measuring survey lines has given the name to this type of survey, the chain is not really necessary. For easier handling and more accurate work, a 100 feet steel measuring tape could be used instead of the chain. A 50 feet or 66 feet steel tape for measuring offsets is

recommended. Builders' roofing laths, if conveniently handy, can be used instead of ranging rods, and various other improvisations will occur to the enterprising surveyor. Nails, hammer, wooden pegs chalk, footrule and a builder's string line should always form part of the equipment.

Choice of Stations and Survey Lines.

When deciding upon the sites of stations for a chain survey, the following points should receive consideration :—

(*a*) To avoid using a cross staff to position long offsets, keep the main survey lines close to the outlines of features which require positioning. If offsets are kept under 30 feet long, the right angle condition can be estimated by eye.

(*b*) A long base line should be established running through the area upon which a series of triangles can be built. See line AB in Fig. 13.

(*c*) All stations should be clearly visible from each other and the ground clear for taking measurements from station to station.

(*d*) The triangles in the framework of stations should be of "robust" proportions, *i.e.*, as far as possible the sides of each triangle should be roughly equal in length and the interior angles not less than 30 degrees to enable accurate office work when plotting.

(*e*) Stations can be marked by ranging rods, but if the duration of the survey prevents the work being completed in one visit, more permanent markings will be required. In open fields timber pegs driven in will suffice; on hard surfaces nails with large flat heads can be driven in flush. All stations should be tied up by measurement with permanent features near at hand to enable the station to be found or re-marked if obliterated. Avoid leaving pegs, nails, etc., in positions likely to injure or cause interference to other persons.

(*f*) Where possible, existing straight boundaries should be utilised as survey lines. (See line AE, Fig. 13).

Boundaries.

If the survey is concerned with the measurement of boundaries, care must be taken to ascertain their exact position, *e.g.*, whether the boundary is the centre-line or the face of a wall or hedge. Local custom varies and reference may have to be made to the title deeds of the land.

Running Survey Lines Round Obstructions.

The line BD passes over a pond. Two methods are indicated to enable the survey line to be taken through this obstruction.

(a) Using a cross staff or optical square, a series of right angles can be laid out, forming a figure GHJK, in which GH equals JK. Offsets can be taken from this figure to establish the outline of the pond.

(b) Alternatively, line in two points G and K with B and D, and establish a third point L, giving a triangle GKL. Fix two points M and N, and the length GK can be obtained by "proportion," the triangles LMN and GLK being similar.

Measurement of Detail not adjacent to Main Survey Lines.

(a) The course of the stream (Fig. 13) is determined by offsets taken from the triangle PQR, which forms a subsidiary figure to the main framework.

(b) To position the pathway, additional lines ST and TV are introduced and offsets taken.

Check Lines.

The number of survey lines contemplated should be kept to a minimum and the framework as simple as possible. To enable the accuracy of the work to be checked, additional measurements between stations are taken. These check lines are not necessary for plotting the framework, but serve as an added safeguard against inaccuracy, *e.g.*, lines CD and BF in Fig. 13.

The Field Book.

The layout of the survey having been decided, the next concern will be recording the information as it is gathered. A field book is used for this purpose and a handy pocket size, with stiff board covers, is recommended. Each page is ruled down the centre with two parallel lines about ½-ins. apart, representing the chain line. The clear space to the left and right is used for booking offset lengths and other data.

A typical page of entries is given in Fig. 14. This example forms part of the line AC in Fig. 13.

Points to note :—

(a) The first page of bookings should consist of a sketch showing the boundaries of the survey, all stations and survey lines. Measured distances between stations can be added as they are obtained. The direction of north in relation to the framework should also be added.

(b) If the survey is likely to be of any duration, positions of all stations will require to be linked up by tie lines with permanent features near at hand and all such dimensions recorded.

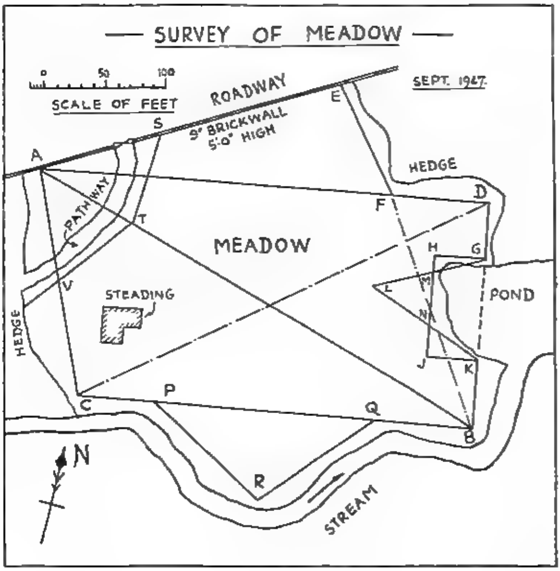


Fig. 13.

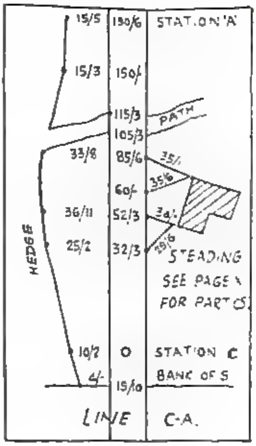


Fig. 14.

(*c*) Always start booking at the foot of the page and work upwards, clearly stating which line is being considered.

(*d*) Distances along the chain line are marked in the centre column and offsets, together with a sketch and description of the feature are entered alongside. The "shillings and pence" method of booking offsets is preferred by most surveyors because of its simplicity. Cramped entries should be avoided.

(*e*) Note the method of showing features that cross the chain line, *e.g.*, the footpath crossing the chain line at 115 feet 3 ins.

(*f*) When it becomes necessary to shout dimensions to the person making entries in the field book, the hearer should repeat the dimension back as confirmation that it has been heard correctly.

(*g*) Field book entries should be of such a standard that another person not acquainted with the survey can understand them.

Amount of Detail Measured.

The amount of detail measured and the accuracy of offsets taken should be related to the scale used for office plotting. Bearing in mind the maximum accuracy with which the length of a line can be plotted on a drawing (say 1/100 part of an inch) and the scale used the degree of error permissible in taking measurements

can be obtained, *e.g.* an error of 1/100 part of an inch in plotting the length of a line to a scale of 30 feet to an inch represents 3·6 ins. In this case extreme refinement in field measurements is unwarranted.

Although it may be possible to allow a degree of error when taking offsets, due to the urgency of the work, it is unwise to allow any error when measuring distances from station to station, as these points may become the basis of calculations and accuracy is essential. Slipshod work will prove a costly business if the field work has to be repeated.

Office Plotting.

Having decided upon the scale and general arrangement of the drawing, the following procedure can be adopted :—

(*a*) The triangulated framework of survey lines is laid down bearing in mind the use of check lines to ensure accuracy.

(*b*) Apply detail to framework. Offsets can be plotted by means of an offset scale, as shown in Fig. 15. The offset scale and main scale are used in the same manner as a set-square and tee-square.

(*c*) The foregoing having been executed in pencilwork, the detail can be lined in with black or coloured inks and the pencil framework erased if it is not required on the finished drawing.

(*d*) The scale, north point, key to symbols used, title, etc., can be added to complete the work. All symbols used for indicating railways, trees, fences, etc., should follow the standard practice laid down by the Government Ordnance Survey Department. Reference to an ordnance survey map will provide this information.

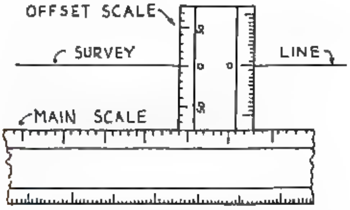


Fig. 15.

Errors in Chain Surveys.

(a) *Errors in Equipment.* The surveyor should satisfy himself that all equipment used is in correct adjustment. Faulty equipment should be rejected and returned to the makers for correction.

(b) *Errors in Procedure.* Incorrect lining in of ranging rods, faulty measurement or booking of particulars are common errors which are very difficult to trace and constant care and attention are required throughout the survey.

LEVELLING.

Practical Application.

The surveyor may be called upon to provide a survey drawing showing the relative differences in height or elevation of points on the earth's surface. A school wall map showing mountain ranges and valleys picked out in colour, is a simple example. Surveys of this nature may be undertaken for various purposes :—

(*a*) To enable a map to be made showing contours, a contour being a line joining all points on the map which have the same elevation above sea level.

(*b*) Before public works, *e.g.*, drainage systems or waterworks are constructed.

(*c*) To enable the amount of excavation required on a building site to be calculated.

(*d*) To consider probable gradients on a proposed road or railway.

Principle.

The basis of levelling consists of establishing a level or horizontal line to which the ground levels of pre-determined points can be related. In Fig. 16 an imaginary level line has been established above a section of sloping ground. If two graduated measuring staves are introduced at A and B, and the heights AD and BC are known, the difference in level of points A and B can be calculated.

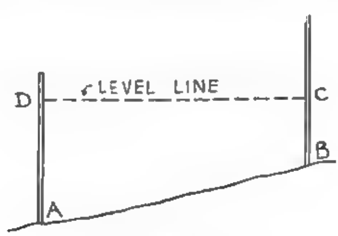


Fig. 16.

Datum Level.

To establish a base line from which a series of different levels can be plotted, all levels must be referred to a datum. In preparing the ordnance survey maps of Great Britain, a datum of mean sea level (fixed at Newlyn, Cornwall, 1926) is adopted. How-

ever, for minor projects, such as a building site, a local datum can be established. A mark on some permanent object near at hand will fulfil this purpose.

Bench Marks.

When desired, local surveys may be referred back to the ordnance datum by means of bench marks. These marks (see Fig. 17) are usually chipped into the stonework of bridges, town halls, etc., by ordnance surveyors and placed at a known height above ordnance datum. To obtain the elevation of these points, reference must be made to the appropriate ordnance survey sheet of 1/2500 scale. Temporary bench marks can be established if required by marking some reasonably permanent object. This is necessary when finishing work for the day and establishing a level to which succeeding work can be related.

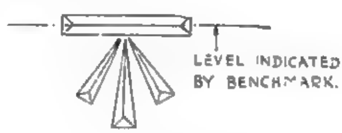


Fig. 17.

The Dumpy Level.

To provide a horizontal line of sight such as the line CD in Fig. 16, a dumpy level is used. The modern dumpy or engineer's level is a smaller and more compact (hence "dumpy") instrument than its earlier predecessors.

The essential parts of the dumpy level are :—

(a) *The Telescope.* The function of the telescope is to provide an enlarged view of the distant measuring staff, thereby permitting accurate reading. Modern dumpy levels are fitted with internal type focussing (*i.e.*, the length of the telescope remains constant whilst being focussed, as against the adjustable length of the older draw tube type of telescope). If the path of reflected light from a distant object is followed through the telescope the image seen by the eye appears inverted and will focus on the line AB.

It is across this line that the diaphragm is located. The diaphragm may be of the following types :—

(i) Fine lines etched on glass.
(ii) Spider's web cross hairs.
(iii) Fine metal points.

The horizontal cross line CD indicates the level line of sight and readings are taken across this line where it cuts the measuring

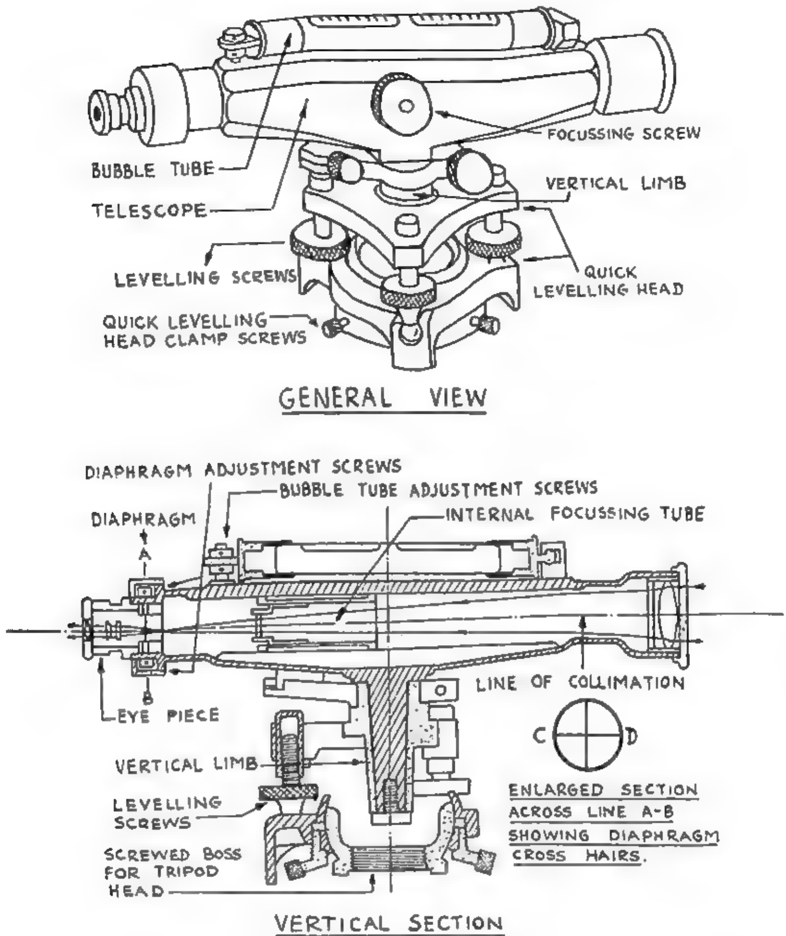


Fig. 18.

staff. This horizontal line of sight is called the "line of collimation." A sun shade is fitted over the front of the telescope to prevent glare when taking readings against the sun.

(b) *Bubble Tube.* To give indication when the line of collimation is level, a curved bubble tube is fitted to the telescope. The line of collimation will be level when the bubble is lying central about the zero mark etched on the bubble tube. A folding mirror is fitted to enable the bubble level to be always in view whilst the eye is applied to the telescope.

(c) *Vertical Limb.* Mounted into the vertical limb the telescope is free to rotate horizontally on its spindle through 360 degrees.

(d) *Levelling Head.* Two metal plates separated by three levelling screws form the levelling head. The upper plate is fixed to the vertical limb of the instrument and connected to the lower plate by three levelling screws. By turning the levelling screws the instrument can be brought perfectly level. To enable the instrument to be fixed to a tripod stand the underside of the lower plate is drilled and screwed. An added refinement is the quick levelling head. On releasing the clamp screws the ball and socket joint is released and the instrument can be rapidly adjusted to an approximately level position. On tightening the clamp, the final adjustment can be carried out by using the levelling screws.

Temporary Adjustments to the Dumpy Level.

Temporary adjustments are carried out each time the instrument is set up before taking readings. The legs of the tripod stand should be firmly planted and the instrument screwed into position. If the instrument is fitted with a quick levelling head, this should be used to bring the bubble tube approximately level. Alternatively, if no such device is fitted, the levelling screws should be roughly at the centre of their run and the tripod legs positioned so that the lower plate is level by eye.

To level up the Instrument.

(*a*) Place the telescope parallel to any two screws A and B as in Fig. 19 (*a*). By manipulating these two screws, bring the bubble tube level. Note that the screws should be turned in the direction indicated by the arrows, either both inwards or both outwards. Turn the telescope through 90 degrees and bring the bubble tube level, using the third screw C. Return the telescope to its original position and repeat the process. When traversed through 360 degrees the bubble should remain central. If this is not the case the instrument is slightly out of adjustment, but this does not matter as long as the bubble is brought level again by use of the levelling screws before taking a reading.

When the instrument has four levelling screws the bubble tube should be placed parallel to any two screws and levelled. Rotate the bubble tube through 90 degrees and level up with the remaining two screws. The process should be repeated until the bubble remains central when rotated. See Fig. 19 (b).

To Focus the Telescope.

By horizontal adjustment of the eye piece the cross hairs on the diaphragm can be brought into sharp focus. Then by using the telescope focussing screw the lenses in the internal focussing system can be moved to bring a distant object into sharp focus. Further adjustment may be needed to either the eye piece or the object lens to ensure that both the cross hairs and the object are in sharp

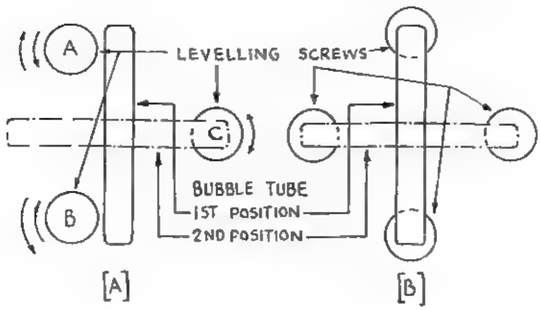


Fig. 19.

focus. The eye piece and object lens are now focussed on the diaphragm. This operation is known as "eliminating parallax." Parallax is said to be eliminated when by moving the eye about no relative movement is observed between the cross hairs on the diaphragm and the object being sighted (*i.e.*, the object is viewed by the eye in the plane of the diaphragm).

The instrument is now ready for use.

The Levelling Staff.

The levelling staff is a graduated measuring stick, upon which sights are taken from the dumpy level. For convenience in handling and transportation, levelling staves are made in sections and can be any of three types :—

(*a*) Socket jointed ;
(*b*) Hinge jointed ;
(*c*) Telescopic.

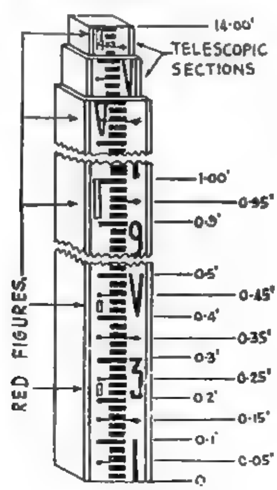


Fig. 20.

In present-day use the telescopic "Sopwith Staff," 14 feet high when extended, is the most popular (see Fig. 20). Advantages of this type are its heavy base for steadiness when holding and the absence of loose pieces, such as pins, required in the joints of types *a* and *b*.

Points to note are :—

(*a*) Each black figure is 0·1 feet high and spaced at 0·1 feet apart.
(*b*) Each 0·1 feet is divided into 10 equal spaces.
(*c*) The tops of the large red figures indicate feet and the smaller red figures indicate which portion of the staff is being sighted when a short sight is taken and a large red figure is not in view.
(*d*) The black diamonds and dots between black figures indicate the mid-point between 0·1 foot markings.
(*e*) Readings appear inverted when viewed through the telescope and readings are reckoned downwards. Staves with inverted numerals can be obtained but are not in common use.
(*f*) Ensure that the "staffman" always holds the staff perfectly vertical. Any discrepancy from left to right is apparent, but if the staff is leaning towards, or away from, the instrument, it is difficult to spot. Instruct the "staff-man" to move the staff backwards and forwards and observe the minimum reading as correct.
(*g*) When the staff is the Sopwith type, care must be taken to see that each length is fully extended and the brass catch restraining the extended length in position.

Permanent Adjustments to the Dumpy Level.

To enable the dumpy level to function correctly, two conditions are necessary :—

(a) *The bubble tube level should be parallel to the line of collimation.*

To check this condition the following test is applied :

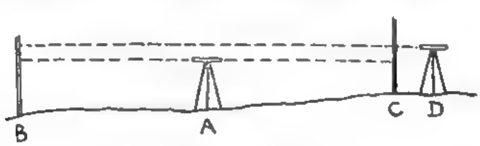


Fig. 21.

Set up three points in line on a fairly level stretch of ground, so that AB equals AC equals 300 feet. Erect and level the dumpy level at A and read on to a staff held at positions B and C respectively. Since the instrument is equally spaced between B and C, any error in the instrument will be cancelled out, and the difference in readings obtained will be the true difference in level between points B and C.

Change the position of the instrument to a point D near to one of the points B or C and again take levels of B and C, calculating a second value for the difference in level.

If the two results agree, the instrument is in correct adjustment. Should this not be the case the diaphragm must be moved vertically by the adjusting screws to bring the line of collimation parallel to the bubble tube level. Great care must be taken to keep the bubble tube perfectly level during this test.

(b) *The bubble tube axis should be perpendicular to the vertical axis through the limb of the instrument.*

After the instrument has been levelled in the normal manner the bubble should remain central in its run if the telescope is traversed to any position. If the bubble tends to run during this movement the deficiency is not serious, as it can be overcome by re-levelling the instrument for each new position of the telescope. Any slight alteration in the line of sight caused by this re-levelling can be ignored.

The error if present is eliminated by bringing the bubble tube parallel to two levelling screws and half the error adjusted by using the levelling screws and half by adjusting the level of the bubble tube screws provided at one end of the bubble tube.

The above adjustments are carried out by the makers during the manufacture of the instrument. Misuse, such as forcing the instrument in or out of its case, using the case as a seat whilst the level is inside and rough handling, will strain and displace the various component parts of the instrument.

Although it is advisable to return the instrument to the makers for any re-adjustment necessary, the surveyor must be able to test the efficiency of his instrument as shown in the above tests.

Should the surveyor desire to correct his own instrument the adjustments in test (*b*) must be carried out before those applicable to test (*a*).

Using the Dumpy Level.

Fig. 22 shows a portion of ground on which it is proposed to use a dumpy level and measuring staff. The basis of the work consists in making a stepped series of levels over the ground.

Level up the instrument at A and take a reading on to a levelling staff held by an assistant (termed the "staffman") at any required positions I. and II. Complete the first stage by taking a reading on to a staff held at position III.

Move the instrument to B, re-level, and take a reading back to the staff which has been retained in position III. This will enable the two instrument positions A and B to be related to each other. Obtain readings as required at positions IV. and V., thus completing the second stage.

The third stage when the instrument is moved to C is a repetition of the second.

It is desirable to start and finish the work by reading the first and last levels with the staff held to a datum mark. This enables all levels to be related to datum as well as providing a basis upon which further work can be built.

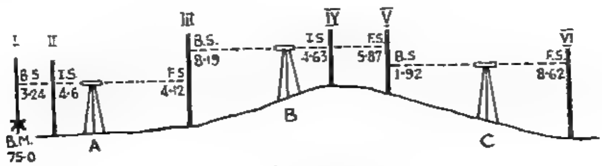


Fig. 22.

Reduced Levels.

The reduced level of any point is its vertical height above a selected datum line. To obtain the reduced level of position II., Fig. 22, proceed as follows :—

Sight I. was taken on to a bench mark of known height (75·00 feet above ordnance datum) and the staff reading was 3·24 feet.
Height of collimation = 75 + 3·24 = 78·24 feet A.O.D.
Sight II. was read as 4·60.
Reduced level of point II. = 78·24 4·60 = 73·64 feet A.O.D.

Back Sights.

On setting up a dumpy level, the first sight taken is referred to as a "back sight" and is taken on to a point of known elevation. In Fig. 22, sights A.I., B.III. and C. V. are back sights.

Fore Sights.

A fore sight is the last sight to be taken before moving the instrument to a new position. The sights A.III, B.V and C.VI. are fore sights. (See Fig. 22).

Intermediate Sights.

These sights are taken to determine the ground level between points at which fore sights and back sights are taken. In Fig. 22, A.II. and B.IV. are intermediate sights.

Change Points.

The points at which the staff is retained whilst the instrument is moved forward are called change points. Points III. and V., Fig. 22, are typical examples.

Recording Levels and Calculating Reduced Levels.

Readings should be entered into a level book of convenient pocket size as soon as they are obtained. Two methods of booking levels are in common use to-day.

(a) *Rise and fall method.*

Back Sight	Inter Sight	Fore Sight	Rise	Fall	Reduc'd Level	Dis-tance	Remarks.
3·24					75·0	0	Bench Mark
	4·60			1·36	73·64		
8·19		4·12	0·48		74·12		Change point
	4·63		3·56		77·68		
1·92		5·87		1·24	76·44		Change point
		8·62		6·70	69·74		Temporary B.M.
13·35		18·61	4·04	9·30			
		13·35		4·04			
		5·26	Fall	5·26	Fall		

Once the reduced level of the first point has been established the reduced level of the succeeding point is obtained by comparing the two readings.

e.g., Reading on point I. $=3{\cdot}24$. Reduced level $=75{\cdot}00$ feet A.O.D.

Reading on point II. $=4{\cdot}6$, representing a fall in level of $4{\cdot}6 - 3{\cdot}24 = 1{\cdot}36$ feet.

Reduced level of point II. $= 75{\cdot}00 - 1{\cdot}36 = 73{\cdot}64$ feet A.O.D.

Note that both readings taken on to a change point have the same reduced level and are entered upon the same line. An arithmetical check can be obtained by comparing the difference in the sum of the back sights and fore sights with the difference in the sum of the rises and falls.

(b) *Height of Collimation Method.*

Back Sight	Inter Sight	Fore Sight	Height of Collimation	Reduc'd Level	Dis-tance	Remarks.
3·24			78·24	75·00	0	Bench mark
	4·60			73·64		
8·19		4·12	82·31	74·12		Change point
	4·63			77·68		
1·92		5·87	78·36	76·44		Change point
		8·62		69·74		Temporary B.M.
13·35		18·61		75·00		
		13·35		69·74		
		5·26	Fall	5·26	Fall	

The basis of this system is the calculation of a height of collimation for each position of the instrument, the reduced levels being obtained by subtracting each reading from the appropriate heights of collimation.

e.g., Height of collimation at point I. $= 75{\cdot}00 + 3{\cdot}24 = 78{\cdot}24$ feet A.O.D.

Reduced level of point II. $= 78{\cdot}24 - 4{\cdot}6 = 73{\cdot}64$ feet A.O.D.

By adding the reduced level to the back sight reading at a change point, the new height of collimation is obtained.

e.g., Height of collimation at

$$B = 74{\cdot}12 + 8{\cdot}19 = 82{\cdot}31 \text{ feet A.O.D.}$$
$$C = 76{\cdot}44 + 1{\cdot}92 = 78{\cdot}36 \text{ feet A.O.D.}$$

The arithmetical check in this case is provided by comparing the difference in the sum of the back sights and fore sights with the difference in the first and last reduced levels.

Comparing the two methods, the second is the simplest to compute, although it will be noted that no arithmetical check is obtained upon the reduced levels calculated from intermediate sights.

This is avoided by using the rise and fall method, as the arithmetical accuracy of each reduced level is dependent upon the correct computation of its predecessors.

Effect of Curvature and Refraction.

The curvature of the earth has an effect upon the accuracy of levelling. In Fig. 23, the line AB is the line of collimation of a dumpy level erected at A and is a tangent to the earth's surface. Point A is therefore a distance of AD above the centroid of the earth. The true height of C above earth's centroid is CD, but the observed height will be BD. BC is the required correction on the height BD.

$$\text{By calculation BC} = \frac{(AB)^2}{\text{Dia. of earth}}$$

Refraction of light, which varies according to climatic conditions, tends to cause droop in the line of sight and will reduce the correction BC by approximately 1/7th.

$$BC = 6/7 \times \frac{(AB)^2}{\text{Dia. of earth}}$$

If AB = 1 mile, BC = 0·57 feet. When sights do not exceed 300 feet to 400 feet the required correction is negligible and can be ignored. Excessive refraction caused on hot sunny days when the staff will appear to "shimmer" can be reduced by shortening lengths of sights.

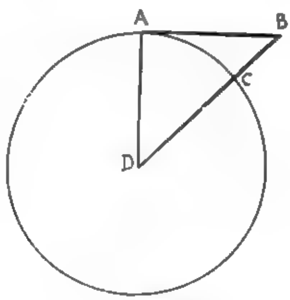


Fig. 23.

Office Plotting.

To illustrate the reduced levels on a survey drawing, two methods are available.

(*a*) By indicating reduced level values in feet, *e.g.* [170·24 ft.] on a plan of the survey.

(b) By plotting a vertical section through the ground, giving a pictorial representation of all changes in level. The vertical scale may be exaggerated in respect to the horizontal.

For general record purposes the first method will prove suitable but for setting out probable gradients on a road or railway, the second method is preferable.

Errors in Levelling.

A series of levels may be checked by starting and finishing the work with sights on to the staff held against ordnance survey bench marks. The total rise or fall computed from the level book should equal the difference in level between the first and last bench marks.

Another method is to take a series of levels (back sights and fore sights only) from the finish back to the starting point, and compare the total difference in levels obtained.

Consideration of the following points will reduce likely errors :—

(*a*) Back sights and fore sights kept equal in length and not to exceed 300 feet to 400 feet.

(*b*) See that the bubble is central in its run, and parallax eliminated before all readings are taken.

(*c*) Change points to be located on firm ground to prevent subsidence of the staff between reading fore sights and back sights.

TRAVERSE SURVEYS.

A traverse survey may be employed where the existing conditions are unsuited to the triangulation required for a chain survey. The principle of the traverse survey is to form a framework of connected lines between stations and to establish their length and relation to each other. If the framework forms a polygon, as in Fig. 24 (a), it is designated a "closed traverse." A series of connected survey lines, as shown in Fig. 24 (b), is known as an "open traverse."

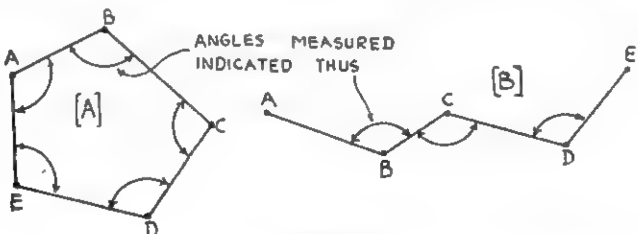


Fig. 24.

The closed traverse would be suitable for surveying the outline of a lake, wood, rough ground, a farm area under crop, or a built-up area in a town where it would be impossible to arrange a series of triangles in the framework of the survey.

To survey a stretch of roadway or the course of a river, the open traverse method would be adopted.

For the measurement of detail adjacent to the survey lines, offsets are used.

Chain Traversing.

The chain is not very adaptable to this form of survey. To establish the direction of survey lines, a series of triangles must be built up and measured at each station point, either external or internal to the framework (see Fig. 25). Even if the space exists for laying out the necessary triangles, a small inaccuracy in measuring or plotting one of the triangles will become magnified when plotting the framework, particularly if the survey lines are long. An angular traverse is more accurate and adaptable.

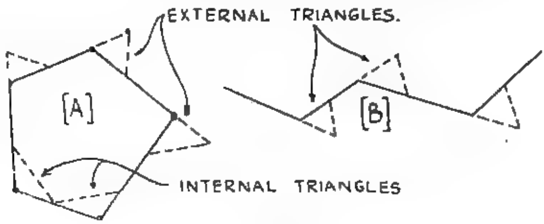


Fig. 25.

Angular Traverse Survey.

The most satisfactory method of obtaining the relationship of the survey lines to each other is by measuring the angles contained in the framework (see Fig. 24).

An alternative method is to divide the framework into a series of imaginary triangles, as in Fig. 26. Each of the triangles CDE, BDE, and ADE has a common base line DE. If this base line and the two base angles for each triangle are measured, the framework ABCDE could be plotted, after calculating the lengths of the remaining sides of the triangles. By measuring a side away from the base line (*e.g.* AB or BC) a check could be obtained upon the accuracy of the work.

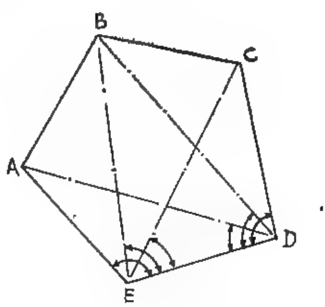


Fig. 26.

It is advisable to keep the number of survey lines to a minimum as the accuracy of the work decreases as the number of sides and angles increases. A modified system of triangulation may be required to stiffen up a weak framework possessing a large number of sides.

THE COMPASS TRAVERSE.

Principle.

Most people will be familiar with the principle of the compass. A freely pivoted and balanced magnetic needle will automatically swing to a definite position, due to the existence of a magnetic field adjacent to the North Pole. The compass traverse is carried out by relating all survey lines to this definite line of reference by angular observation, and the angle measured is termed a "bearing." By using a compass to measure angles a large number of observations can be taken quickly and with a fair degree of accuracy, say 10 to 15 minutes of a degree. This speed and ease of handling make the compass a useful instrument when great accuracy is not desired.

Magnetic Meridian.

The line of direction indicated by a compass needle when allowed to pivot freely and become stationary is known as the magnetic meridian. This meridian lies slightly to the west of the true North-South meridian in this country and the angle formed between the two is called the angle of declination.

The value of the angle of declination varies (*a*) annually and (*b*) according to location. In this country the variation ranges from approximately 9 degrees on the east coast of England to 14 degrees in Ireland. Reference to the appropriate ordnance survey sheet will give the value for each locality.

Local Attraction.

A compass needle may be deviated from its true meridian by local attraction caused by the presence of iron, steel and electric cables in the neighbourhood of the needle. All observations must therefore be made in such a manner as to detect local interference.

Bearings.

It is only proposed to deal with the simplest method of reading bearings, known as the "whole circle" or "azimuth" method.

When using this method, all bearings are measured clockwise, in degrees, from the magnetic or true north meridian, the full circle being divided into 360 degrees. Thus in Fig. 27 the bearing or azimuth of the lines OB, OC and OD are :—

Bearing of line OB = angle *b*
,, ,, OC = angle *c*.
,, ,, OD = obtuse angle *d*.

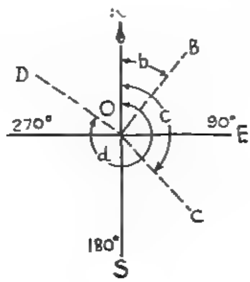


Fig. 27.

Forward and Backward Bearings.

In Fig. 28, the line AB, reading from A to B, is said to have a forward bearing of *a* degrees and a backward bearing of *b* degrees. The adjectives "forward" and "backward" are merely indicative of direction along the line AB, using A as a starting point. It will be noted that the forward and backward bearings of the line AB should differ by 180 degrees. If not an average value must be obtained.

e.g., forward bearing of AB = 43 degrees.
backward ,, ,, = 225 ,,
225 — 180 = 45 degrees.

averaged forward bearing of AB $= \dfrac{43+45}{2} = 44$ degrees

If local attraction is present, larger differences will occur between forward and backward bearings. When carrying out a compass traverse, inspection of results will show which bearings are likely to be in error, and adjustments can be made during plotting, at the surveyor's discretion.

Fig. 28.

The Prismatic Compass.

For the surveyor, this instrument is the most useful and easily handled of the various compasses at his disposal.

The compass may be obtained in various sizes up to 6 ins. diameter, the larger types being fitted with a screwed boss to enable the instrument to be fixed to a short staff or tripod.

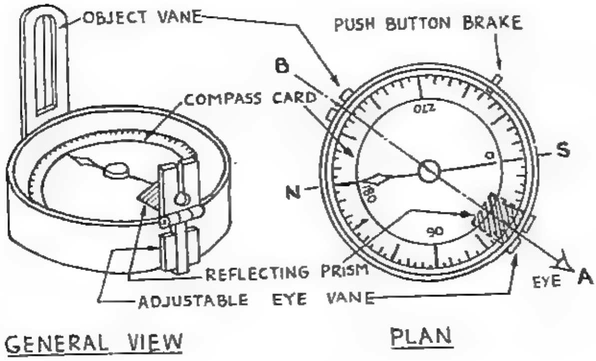


Fig. 29.

A sight is obtained, using the two collapsible sighting vanes, and the addition of a reflecting prism at the eye vane enables the vertical cross hair in the object vane to be sighted whilst observing the movement of the compass card. The reading is taken where the cross hair in the object vane cuts the reflected image of the compass card.

The floating magnetised needle carries the compass card which is divided into degrees. A small push button brake is provided to damp the swing of the compass card whilst a reading is observed. When the instrument is not in use the action of folding down the object vane lifts the compass needle from its pivot and secures it against movement. By this means the sensitive needle suspension is not impaired.

To obtain the bearing of the line AB (see Fig. 29) the instrument is held at A and a sight taken to B, along the line AOB. The bearing required will be the angle NOB, but the observed angle taken at the "south" end of the instrument will be angle AOS. So that a direct reading can be taken the graduations on the compass card are reversed, the zero being positioned at the south point of the compass needle, graduations proceeding clockwise.

Plotting the Compass Traverse.

Fig. 30 shows the boundaries of a plot of land which have been surveyed by chaining the sides AB, BC, CD and DA, and observing the bearings of points A, B, C and D, the whole being plotted, using a scale and protractor.

Before plotting the traverse survey the interior angles contained in the framework should be calculated and their sum checked against the correct total for that particular figure. The sum of the interior angles of a figure having n sides is $180\ (n-2)$ degrees. Any difference obtained should be divided amongst the bearings

(not the interior angles) in proportion to the length of side to which they belong. Although not strictly accurate the above method is justifiable when the accuracy of field work and plotting of this type of survey is borne in mind. If a more accurate traverse survey is required the theodolite is used.

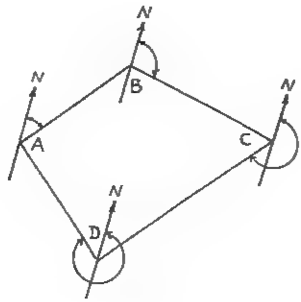


Fig. 30.

THE THEODOLITE TRAVERSE.

General Description of the Theodolite.

The theodolite is the most accurate instrument, for measuring angles, available to the surveyor.

Of many types manufactured, the transit theodolite, capable of measuring vertical and horizontal angles, is the most popular. The adjective transit indicates that the telescope can be rotated through 360 degrees in the vertical plane.

The Levelling Head. The theodolite levelling head is roughly similar to that fitted to the dumpy level. An important addition is the plumb bob indicating the centroid of the instrument, thus allowing it to be set up precisely over a station point.

The Lower and Upper Plates. Fitted to the lower plate is the graduated measuring circle and the action of traversing a fixed mark on the upper plate against this graduated circle is the method adopted for measuring horizontal angles. Both plates are capable of free horizontal motion by means of an inner and outer spindle mounted in the levelling head. Instruments may be fitted with a quick centring device. By releasing the centring clamp the upper part of the instrument is free to slide on the levelling head, allowing a quicker and a greater degree of accuracy when positioning the plumb bob exactly over a station. The movement is locked by re-tightening the centring clamp.

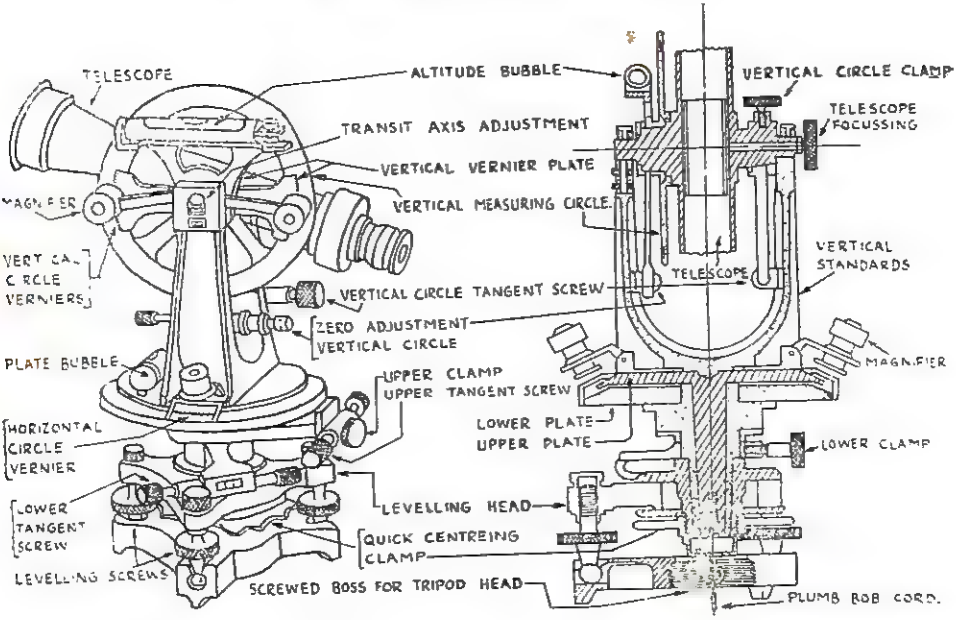


Fig. 31.

Vertical Measuring Circle and Standards.—Attached to the upper plate are two vertical standards carrying the horizontal axis about which the telescope and vertical measuring circles rotate together. To measure a vertical angle the telescope and vertical circle are rotated past a fixed horizontal mark on the vertical vernier plate. The vertical vernier plate is mounted on one of the standards but is capable of movement about the horizontal axis for adjustment purposes.

Bubble Tubes.—To enable the instrument to be set up perfectly level bubble tubes are fitted. One or two are mounted on the upper plate to enable the horizontal circle to be levelled, and if two are provided they are mounted at right angles to each other. Another bubble is either mounted on the telescope, or fixed to the vertical vernier plate and gives indication of a horizontal zero for the vertical circle.

Clamp and Tangent Screws. So that a greater degree of accuracy can be obtained when measuring angles with the theodolite, a slow motion action is fitted enabling slight adjustments to be made as required. For this purpose, clamps and tangent screws are fitted to the horizontal and vertical circles. The application of the clamp locks the movement and any slight adjustment required to bring the telescope line of sight exactly upon the desired point can be

made by rotating the tangent screw. Three sets of clamps and tangent screws are fitted :—

(*a*) Lower clamp to lock movement of lower plate.
(*b*) Upper clamp to lock upper plate with lower plate.
(*c*) Vertical circle clamp to lock movement of vertical circle and telescope.

Verniers. To enable accurate readings to be obtained, direct reading verniers are provided on the upper plate and vertical circles at the zero and 180 degree points. Magnifiers are fitted for easy reading of the verniers.

A simple example of the vernier is shown in Fig. 32 (a). The main scale is divided into tenths and the vernier scale such that nine divisions on the primary scale are equal to ten on the vernier. It will be seen that if the zero on the vernier scale lies 1/10 of a division past a division mark on the primary scale the first division on the vernier scale will coincide with the next division on the primary scale, indicating a reading of 10·1.

In Fig. 32 (b) the vernier zero lies 3/10 of a division past the 10·2 mark, this being indicated by the 3rd mark on the vernier coinciding with the 10·5 mark on the primary scale, and indicating a reading of 10·23 (*i.e.*, the third division on the vernier scale coincides with the third division past the 10·2 reading on the primary scale).

Applied to surveying instruments the vernier may be of varying accuracy according to the quality of the instrument. The degree of accuracy to which a vernier can be read is termed its "least count" and is equal to d/n, where d = value of 1 smallest division on the primary scale and n = number of individual spaces on the vernier scale (not the largest numeral indicated, *e.g.* in the Fig. 32 (c), the vernier is numbered up to 20, but has 60 small spaces).

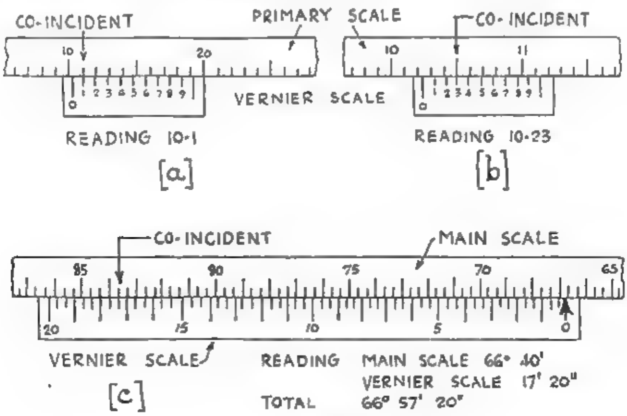


Fig. 32.

Least count of vernier scale in Fig. 32 (c) = 1/3 of a degree, divided by 60 = 20 seconds.

Reading the example in Fig. 32 (c) the reading on the main scale is 66 degrees 40 minutes and a reading on the vernier scale of 17 minutes 20 seconds, giving a total reading of 66 degrees 57 minutes 20 seconds. In this case, 59 main scale divisions are equal to 60 vernier divisions.

The Magnetic Compass. To enable readings of horizontal angles to be related to the north meridan a magnetic compass can be clipped to the instrument.

The Telescope. The telescope fitted to the theodolite is similar to that employed in the dumpy level, the diaphragm cross hairs being of the type illustrated in Fig. 18. When sighted on to a station mark, the telescope is set so that the diaphragm cross hairs bisect the station mark both horizontally and vertically.

Although the inverted image may be considered troublesome, very few surveying instruments have correcting lenses fitted. The objections are :—

(*a*) the introduction of two more lenses required to correct the image tends to obscure the passage of light ;

(*b*) for a given length the inverted lens telescope is more powerful.

Temporary Adjustments to the Theodolite.

Temporary adjustments to the theodolite are carried out each time the instrument is set up prior to taking readings.

The procedure is :—

(*a*) After erecting the theodolite on its tripod, the plumb bob must be brought exactly over the station point by manipulating the tripod legs and using the quick centring device if fitted.

(*b*) The instrument is levelled up in a similar manner to the dumpy level, if only one plate bubble is provided. If two plate bubbles are fitted, the procedure is identical, but it will not be necessary to turn the instrument through 90° before using the third levelling screw. The lower clamp should be engaged and the upper clamp free when making this adjustment.

(*c*) Eliminate parallax as for the dumpy level.

Permanent Adjustments to the Theodolite.

Before leaving the makers, the instrument is adjusted so that all readings observed will be accurate. Mis-use of the instrument will damage and strain the various parts and it should be returned to the makers periodically for a thorough examination and adjustment.

If a check procedure is used when making all observations it will not be necessary for the surveyor to make any alterations to the permanent settings, but the surveyor should be able to test and detect any deficiency in his instrument.

(a) *The adjustment of the Plate Bubbles.* The upper plate is used for measuring horizontal angles and it is important that this plate is truly level and the vertical standards consequently truly vertical.

When the instrument has been set up and levelled it should be possible to traverse the upper plate through 360 degrees and the plate bubble remain level. Should this not be the case the bubble should be brought level by adjusting the bubble tube nuts provided and the test repeated. The bubble fixed to the vertical vernier plate may not indicate a level condition, but should remain a fixed amount off centre whilst the upper plate is rotated. If two bubbles are fitted to the upper plate, one should only be used for the above test and the second adjusted to suit the first.

(b) *To ensure that the line of collimation is at right angles to the transit axis of telescope.* Set up and level the theodolite and set the horizontal circle verniers to zero and 180 degree marks, using the upper clamp and tangent screw. Clamp the telescope approximately level and direct a sight exactly on a mark, using the lower clamp and tangent screw. Release the upper clamp and turn the horizontal circle through 180 degrees, re-clamp and set accurately, using the upper tangent screw. Transit the telescope and it should read back exactly on the previous mark. If not, any error is caused by the vertical diaphragm cross line not being in the line of sight. The action of transiting the telescope through 180 degrees has doubled the error which may be corrected by adjusting the horizontal diaphragm screws, and bringing the vertical diaphragm cross line perpendicular to the transit axis.

(c) *To test whether the transit axis of the telescope is level* (*or, at right angles to the vertical axis*). Level up the instrument, engage the upper clamp and sight on to a mark at about 45 degrees elevation (*e.g.*, a church steeple A in Fig. 33), using the lower and vertical circle clamps and tangent screws. Release the vertical circle clamp, depress the telescope and mark the spot B on the

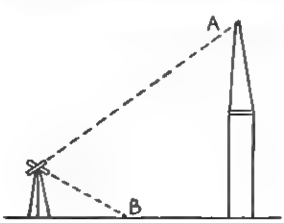


Fig. 33.

ground which is bisected by the diaphragm cross hairs. Release the upper clamp, turn the horizontal circle through 180 degrees exactly, and re-sight accurately on A. Depress the telescope again and the line of sight should bisect mark B. Should the instrument be at fault, the level of the transit axis can be corrected by the nuts provided.

It is important that the instrument is kept perfectly level during this test.

(d) *To bring the vertical circle to read zero when the altitude bubble is level.* Level the theodolite, using the plate bubble, and bring the altitude bubble level by means of the zero adjusting screws. Set the vertical circle to zero, using the vertical circle clamp and tangent screws, and take a reading on to a levelling staff placed about 150 feet away. Turn the horizontal circle through 180 degrees, transit the telescope, bring the vertical circle to zero, and obtain another reading on the staff. If the readings do not coincide, correct the error by :—

I.—Set the horizontal diaphragm cross hairs to the average of the readings obtained by using the vertical circle tangent screw.

II. Bring the vertical verniers to zero by means of the zero adjustment screws.

III. Level the vernier bubble, using the nuts provided on the bubble tube.

Using the Theodolite in Traverse Surveys for Measuring Horizontal Angles.

(*a*) Set up the theodolite over the station (*e.g.*, point 0, Fig. 34), level up, and eliminate parallax as previously described. The instrument will now be ready for use, the lower and vertical circle clamps fixed and the upper clamp free.

(*b*) Rotate the upper plate until the vernier zero marks are brought approximately to the zero and 180 degree points on the lower plate. Engage the upper clamp and using the tangent screw set the vernier zeros exactly to zero and 180 degree points. Book the readings of both horizontal circle verniers.

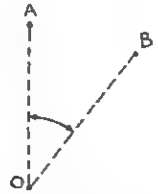


Fig. 34.

(*c*) Free the lower clamp, allowing both plates and the telescope to rotate together. Bring a sight to bear on the distant point A, engage the lower clamp and by using the lower tangent screw bring the diaphragm vertical cross hairs to bisect the point A. The vertical circle clamp and tangent screw will be required to bring the horizontal cross hairs, exactly on the point A.

(*d*) Release the upper clamp and swing the telescope until point B can be seen, refix the upper clamp and bring the cross hairs exactly to the point B, using the upper tangent screw.

(*e*) Read both verniers, giving the value of the angle AOB. The two vernier readings should differ exactly by 180 degrees, any discrepancy should be averaged out and the mean taken as the correct reading. By reading both verniers, instrumental errors are minimised.

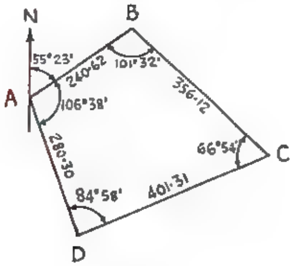
(*f*) To check the readings the instrument can be "changed face" and the readings re-taken. If the vertical circle lies to the left hand side of the telescope, the instrument is said to be in the "face left position." By swinging the telescope through 180 degrees on the horizontal circle, the vertical circle will now be on the right of the telescope, or in the "face right position." All readings should be checked by changing face, reading both verniers, and averaging the results. Any serious differences in the readings will point to an error having been made in the handling of the instrument, and the work must be re-done.

Field Procedure

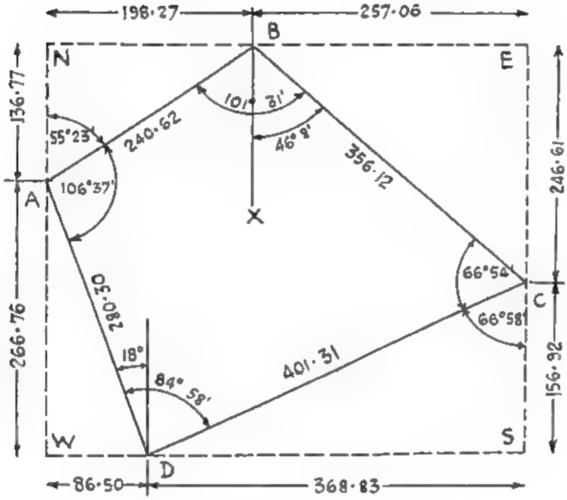
Assuming ABCD, Fig. 35 (a) to be the four stations of a traverse survey, the following procedure is adopted :—

(*a*) On setting up the instrument at A, the bearing of line AB is established. After fixing the compass to the instrument, set the upper plate verniers exactly to zero, release the lower clamp and swing the telescope until the compass needle lies roughly in the north-south meridian. Set the lower clamp and use the lower tangent screw to bring the compass needle exactly on to the meridian. The line of sight now lies in this meridian. Release the upper clamp and take an exact line of sight on to B, using the appropriate tangent screws. The bearing of line AB is obtained by reading the verniers.

(*b*) Using the procedure previously described, the horizontal included angles at A, B, C and D can be measured. It will be noted that each station will then have been taken clockwise, and each angle also measured clockwise in a systematic manner. If the angles are measured anti-clockwise, care must be taken in reading the verniers as the horizontal circle is graduated clockwise (*i.e.*, the readings must be subtracted from 360 and 180 degrees according to which vernier is read).



[a]



[b]

Fig. 35.

Booking the Results.

To avoid confusion, follow a systematic procedure when reading and booking angles, *e.g.*, all angles to be read clockwise, firstly in the face left position and then in the changed face position, and an average value obtained and entered thus:—

Line	Face Left		Face Right		Corrected Reading	Remarks.
	0°	180°	0°	180°		
XY	30°37′	210°38′	30°36′	210°37′	30°37′	Angle XYZ

The field bookings should also record all measurements taken and a sketch of the survey framework. Offsets can be taken and booked in a similar manner to that previously described for the chain survey.

Precautionary Measures when carrying out a Theodolite Traverse.

(*a*) Always sight the theodolite on to the lowest point of the station, because the station marking poles may not be plumb.

(*b*) The surveyor must clearly understand the effect of using each clamp and tangent screw. By confusing the tangent screws with each other a wrong movement may be made and incorrect results observed.

(*c*) Extra care should be taken when measuring the sides forming the framework. A steel tape carefully used will give a degree of accuracy in keeping with the accuracy of the measured angles.

Plotting the Traverse Survey by using Co-ordinates.

The accuracy demanded in plotting a theodolite traverse survey framework, rules out the possibility of using a scale and protractor. A much greater degree of accuracy can be obtained by plotting the survey lines, using co-ordinates, the north-south, east-west compass quadrant points taking the place of the x and y co-ordinates used in mathematics.

Latitudes and Departures.—Referring to Fig. 36, the co-ordinates used in plotting the line OA will be OE and EA, for OB, OF and FB and for OC, OG and GC. For the purpose of designation, all co-ordinates, measured north from a point are termed "northings," those measured south, "southings"; east, "eastings"; and west, "westings". In addition, all co-ordinates measured north or south are termed latitudes and all co-ordinates measured east or west, departures.

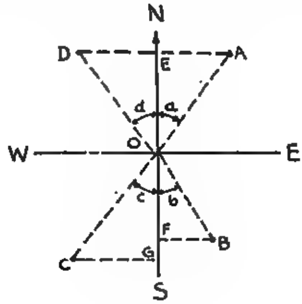


Fig. 36.

Thus, line OA has a latitude of OE and a departure of EA. Let the bearing of the line OA be a degrees :—

Then latitude OE of point A = OA cosine a degrees.
and departure EA „ „ = OA sine a degrees.

Reduced Bearings. In calculating the co-ordinates of points A, B and C (Fig. 36) the values of the sine and cosine of angles a, b and c will be used. Each angle is related to the north-south meridian and is called the reduced bearing, *e.g.* the reduced bearing of line OB is angle b. To fix the quadrant in which each bearing lies, the cardinal points N, S, E and W are used.

e.g., The reduced bearing of line OA = N a degrees E.
„ „ „ „ OB = S b degrees E.
„ „ „ „ OC = S c degrees W.
„ „ „ „ OD = N d degrees W.

Procedure in Computing Co-Ordinates.

Fig. 35 (a) is an example of a four-sided traverse survey framework as measured in the field, showing the lengths of the sides and the corrected field readings of the angles. The co-ordinates required for plotting the survey will form a rectangle NESW, as indicated in Fig. 35 (b).

(a) *Balancing the Angles measured.*

Angle	Corrected Observed Reading	Final Correction for Plotting
A	106°38′	106°37′
B	101°32′	101°31′
C	66°54′	66°54′
D	84°58′	84°58′
Total	360°2′	360°0′

The sum of the interior angles of a four-sided polygon being 360 degrees, the total for the survey is in excess of this figure by 2 minutes. Balance the angles by distributing the difference where it will cause least displacement to the survey, *i.e.*, in the biggest angles. The angles A and B are the largest, therefore one minute is subtracted from each.

(b) *Calculate the reduced bearings of all stations*, commencing at A and proceeding clockwise.

Reduced bearing of AB = N 55° 23′ E as observed in field.
„ „ BC = Angle XBC

To find angle XBC

$$\begin{aligned}
&\text{angle NAB} = \text{angle ABX} = 55^\circ\,23' \\
\text{then } &\text{angle XBC} = (\text{angle ABC}) - (\text{angle ABX}) \\
&\qquad\quad = 101^\circ\,31' - 55^\circ\,23' = 46^\circ\,8'
\end{aligned}$$

Reduced bearing of BC = S 46° 8′ E.
Reduced bearing of CD = angle DCS.

To find angle DCS

$$\begin{aligned}
\text{angle XBC} &= \text{angle BCE} \\
\text{angle DCS} &= (180 \text{ degrees}) - (\text{angle BCE}) - (\text{angle BCD}) \\
&= (180) - (46^\circ\,8') - (66^\circ\,54') = 66^\circ\,58'
\end{aligned}$$

Reduced bearing of CD = S 66° 58′ W.
Similarly, reduced bearing of AD = N 18° W.

(c) *Calculate Co-ordinates.* Commencing at point A, the co-ordinates of station B are a northing AN, and an easting NB.

AN = AB cosine 55° 23′ = 136·69 ft. latitude.
NB = AB sine 55° 23′ = 198·02 ft. departure.

Proceeding clockwise, the co-ordinates of station C are a easting BE, and a southing EC.

BE = BC sine 46° 8′ = 256·73 ft. departure.
EC = BC cosine 46° 8′ = 246·77 ft. latitude.

Proceeding clockwise, the co-ordinates of station D are a southing CS and a westing SD.

CS = CD cosine 66° 58′ = 157·02 ft. latitude.
SD = CD sine 66° 58′ = 369·31 ft. departure.

Proceeding clockwise, the co-ordinates of station A are a westing of DW and a northing of WA.

DW = DA sine 18° = 86·61 ft. departure.
WA = DA cosine 18° = 266·58 ft. latitude.

All values as obtained are entered in the table illustrated in Fig. 37.

LINE	LENGTH	CORR'TD ANGLE	STATION	REDD' BEAR'G	CALCULATED LATITUDES N	CALCULATED LATITUDES S	CALCULATED DEPARTURES E	CALCULATED DEPARTURES W	CORRECTED LATITUDES N	CORRECTED LATITUDES S	CORRECTED DEPARTURES E	CORRECTED DEPARTURES W
AB	240·62	106° 37′	A	55° 23′	136·69		198·02		136·77		198·27	
BC	356·12	101° 31′	B	46° 8′		246·77	256·73			246·61	257·06	
CD	401·31	66° 54′	C	66° 58′		157·02		369·31		156·92		368·83
DA	280·30	84° 58′	D	18°	266·58			86·61	266·76			86·50
					403·27	403·79	454·75	455·92	403·53	403·53	455·33	455·33
						403·27		454·75	FINAL CO-ORDINATES FOR PLOTTING			
						0·52		1·17				

Fig. 37.

Balancing the Survey.

For the survey to balance, the sum of all the northings should equal the sum of all the southings and the westings equal the eastings.

Due to instrumental and human errors this will not be the case. For instance, the southings exceed the northings by 0·52 feet and the westings exceed the eastings by 1·17 feet. To balance the survey these differences must be divided amongst the latitudes and departures in proportion to their length.

To balance the northings and southings.
Excess = 0·52 ft. southing.
Total latitudes = 136·69 + 266·58 + 157·02 + 246·77 = 807·06

$$\text{Error per foot of latitude} = \frac{0{\cdot}52}{807{\cdot}06} \text{ feet.}$$

$$\text{Error in northing AN} = 136{\cdot}69 \times \frac{0{\cdot}52}{807{\cdot}06} = 0{\cdot}08 \text{ added.}$$

$$\text{,, ,, WA} = 266{\cdot}58 \times \frac{0{\cdot}52}{807{\cdot}06} = 0{\cdot}18 \text{ added.}$$

$$\text{Error in southing EC} = 246{\cdot}77 \times \frac{0{\cdot}52}{807{\cdot}06} = 0{\cdot}16 \text{ deduct.}$$

$$\text{,, ,, CS} = 157{\cdot}02 \times \frac{0{\cdot}52}{807{\cdot}06} = 0{\cdot}10 \text{ deduct.}$$

The corrected latitudes are now entered in the appropriate column, and the departures treated in a similar manner.

Plotting may now be carried out, commencing from station A, fixing each succeeding station in turn by plotting its appropriate co-ordinates.

FURTHER APPLICATION OF THE THEODOLITE.

Measuring Vertical Angles.

Before measuring vertical angles it is important to check that the plate and altitude bubbles are in correct adjustment.

Finding the height of a tall building (Fig. 38) is a simple application of the theodolite when used for measuring vertical angles.

(*a*) Bring the vertical circle zero exactly opposite the vernier zero, using the vertical circle clamp and tangent screw.

(*b*) The telescope now being perfectly level, take a sight on to a levelling staff held against the building at D.

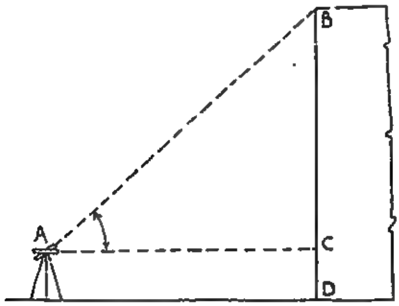


Fig. 38.

(*c*) Release the vertical circle clamp and sight on to a point on the roof of the building exactly above D. Re-engage the clamp and use the tangent screw to give an accurate sight. Read both verniers and obtain a value for the angle BAC.

(*d*) Change face and repeat, obtaining an average value for angle BAC.

(*e*) Measure AC. Then BC = AC tangent BAC and height of building, BD = BC + CD.

Tacheometry.

Should the theodolite be fitted for tacheometry, horizontal distances can be measured very rapidly.

The diaphragm has two additional cross hairs fitted, termed "stadia lines" (see Fig. 39).

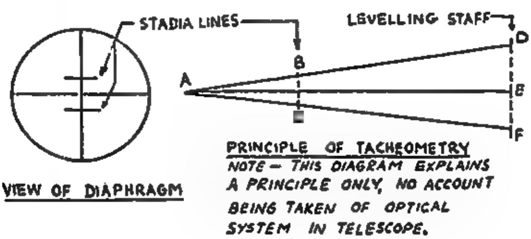


Fig. 39.

By reading on to a levelling staff placed at E, the length of staff DF, subtended by the stadia lines can be ascertained.

The distance apart of the stadia lines BC and the distance of the diaphragm from the optical centre of the instrument being known, ABC and ADF are similar triangles from which AE can be calculated.

To simplify calculations, the instrument makers provide set relationships between these variable quantities. An instrument may be set so that for each 100 feet of horizontal distance the stadia lines will subtend 1 foot of levelling staff. To this must be added a fixed constant depending upon the optical system with which the telescope is fitted.

e.g., A certain instrument will subtend 1 foot of levelling staff for each 100 ft. of distance and the constant given by the makers of the instrument is 1·75. What is the distance of the theodolite from a levelling staff when the stadia lines subtend a reading of 2·03 feet?

Distance, $2{\cdot}03 \times 100 + 1{\cdot}75 = 204{\cdot}75$ feet.

It will be noted that the levelling staff is read to 1/100 of a foot and the distance is consequently only accurate to the nearest foot. For accurate work a staff reading to 1/100 part of a foot is not suitable, but if the survey was plotted to a small scale (*e.g.* 1/200), the error could be ignored.

BIBLIOGRAPHY.

For a brief introductory reading:

"Encyclopaedia Britannica," Vol. 21.
Elementary Surveying, A. L. HIGGINS.
Longmans, Green & Co., 1943.

A comprehensive manual:

"Plane and Geodetic Surveying." D. CLARK.
Volume I., Plane Surveying.
Volume II., Higher Surveying.
Constable and Co., Ltd. Fourth edition, 1946.

A text-book on American methods:

"Engineering Surveys, Elementary and Applied." RUBEY, LOMMEL & TODD. MacMillan Co., New York, 1942.

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23. 1" " " " "
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25. $\frac{7}{8}$" " " " (30 ton yield).
26. 1" " " " (30 ton yield).
27. $\frac{3}{4}$" " " " (40 ton yield).
28. $\frac{7}{8}$" " " " (40 ton yield).
29. 1" " " " (40 ton yield).
30. Moments of Inertia of Built-up Sections (Tables).
31. Moments of Inertia of Built-up Sections (Instructions and Examples). } Connected.
32. Reinforced Concrete Slabs (Line Chart).
33. Reinforced Concrete Slabs (Instructions and Examples). } Connected.
34. Capacity and Speed Chart for Troughed Band Conveyors.
35. Screw Propeller Design (Sheet 1, Diameter Chart).
36. " " " (Sheet 2, Pitch Chart).
37. " " " (Sheet 3, Notes and Examples) } Connected.
38. Open Coil Conical Springs.
39. Close Coil Conical Springs.
40. Trajectory Described by Belt Conveyors (Revised 1949).
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42. Useful Conversion Factors.
43. Torsion of Non-Circular Shafts.
44. Railway Vehicles on Curves.
46. Coned Plate Development.
47. Solution of Triangles (Sheet 1, Right Angles).
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74. Journal Friction on Bearings.
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78. Velocity of Flow in Pipes for a Given Delivery. } Connected.
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105. Permissible Working Stresses in Mild Steel Struts to B.S. 449, 1948.

(Data Sheets are 3d to Members, 6d to others, post free).

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